REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	July 25, 1996	FINAL REPORT April 15, 1993 through May 31, 1996

4. TITLE AND SUBTITLE Multidimensional Digital Signal Processing, Optical Devices for Information Processing, and Electromagnetic Analysis and Measurement

5. FUNDING NUMBERS

DAAH04-93-G-0027

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8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

U. S. Army Research Office
P. O. Box 12211
Research Triangle Park, NC 27709-2211

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

ARO 30865.39-EL-JSEP

11. SUPPLEMENTARY NOTES

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12a. DISTRIBUTION/AVAILABILITY STATEMENT

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12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

This is the final report on research carried out under this contract. There has been significant progress in the research areas of multidimensional digital signal processing and modeling, iterated function systems and stereo image processing, morphological systems for multidimensional signal processing, time-frequency-wavenumber representations, optical devices for information processing, semiconductor quantum wave devices, electromagnetic measurements in the time and frequency domains and in microwave holography in near- and far-field measurements. This report lists degrees awarded and publications for the three-year contract period. Specific research results are contained in the Annual Reports submitted prior to this final report.

14. SUBJECT TERMS	15. NUMBER OF PAGES
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

Contents

1 Overview

This is the Final Report on research carried out under Contract DAAH-04-93-G-0027. The period of the contract is from April 15, 1993 through April 14, 1996. The research is part of the Joint Services Electronics Program (JSEP) and is administered by the U.S. Army Research Office. The report is concerned with basic research in the following broad areas of electronics:

- Multidimensional signal processing,
- Optical information storage and processing,
- Electromagnetic measurements.

The three year period covered by the contract has produced significant progress in all these areas. Detailed discussion of progress during the contract period is given in the three preceding annual reports. This report lists only degrees granted and publications during the contract period. The main topics of research are given in the following subsections for each of the three main areas of research.

1.1 Research in Multidimensional Signal Processing

During the past three years the research in this area has been carried out in four work units. These work units have focused on multidimensional signal processing and modeling, iterated function systems, stereo image processing, morphological (nonlinear) signal processing systems, filter banks, and array processing. Specific research topics discrete-cosine transforms, multidimensional multirate filter banks, motion estimation and compensation for video sequence analysis, model-based video compression, objective quality measures for assessing subjective video quality, interpolation of video sequences, video compression, image identification and restoration in the frequency-wavelet domain, iterated function systems in image and video coding, processing and coding of stereo image pairs, image segmentation using connected filters, template matching using min/max operations, critical morphological sampling theorems, morphological filters in pyramid image coding, time varying filter banks, resolution variant filter banks, cosine modulated and statistically optimal filter banks, complex filter design, the angular Fourier transform, hybrid array characterization, multidimensional signal processing design using Mathematica, and many more topics in multidimensional digital signal processing.

1.2 Research in Optical Information Storage and Processing

In the optical storage and processing part of the contract, the research was carried out in two work units which focused on the design, fabrication, and testing of devices for high-speed optical/electronic information processing and on the understanding and design of semiconductor nanometer-scale structures. Specific research topics include rigorous coupled wave analysis for binary, surface-relief, and multilevel gratings; subwavelength grating devices;

diffractive waveguide couplers; optimization of waveguides and waveguide sensors; phase stability of liquid crystals; optimization of multilayer integrated optics waveguides; optical interconnect technology for parallel computation; determination of energies and lifetimes of bound and quasibound states; time response of quantum resonant structures; electron waveguides; infrared lasers based on quasibound electron energy levels; quantum transmittance across single interfaces; electron grating switch and broadcast devices; low-temperature scanning tunneling microscope for ballistic emission microscopy and spectroscopy; and many other topics related to optical and semiconductor quantum devices.

1.3 Research in Electromagnetic Measurements

In this area of the contract, the work was carried out in two work units that focused on electromagnetic measurements in the time and frequency domains and on near- and far-field antenna measurements. Specific research topics in this area include pulse excited antennas, ground penetrating radar, circular loop antennas with coaxial feed, spherical microwave holography for antenna and radome diagnostics, antenna range enhancement and compensation and many other topics in electromagnetic modeling and measurement.

1.4 Organization of Report

The next section gives a list of the work units and their principal investigators. Following that is a list of doctoral degrees awarded. Twenty-one Ph.D. degrees were awarded to students who were supported by this contract. Thesis topics spanned the complete range of topics covered by the contract. Finally, the last section consists of a complete lists of publications and patents that resulted from the research during the period of the contract.

2 Work Units and Principal Investigators

Work Unit One: *Multidimensional Digital Signal Processing and Modeling*
Principal Investigator: Russell M. Mersereau, Regents' Professor

Work Unit Two: *Iterated Function Systems and Stereo Image Processing*
Principal Investigator: Monson H. Hayes, Professor

Work Unit Three: *Morphological Systems for Multidimensional Signal Processing*
Principal Investigator: Ronald W. Schafer, Institute Professor

Work Unit Four: *Multidimensional Time-Frequency-Wavenumber Representations*
Principal Investigators: James H. McClellan and Mark. J. T. Smith

Work Unit Five: *Optical Devices for Information Processing*
Principal Investigators: E. N. Glytsis and T. K. Gaylord

Work Unit Six: *Semiconductor Quantum Wave Devices*
Principal Investigators: T. K. Gaylord and E. N. Glytsis

Work Unit Seven: *Electromagnetic Measurements in the Time- and Frequency-Domains*
Principal Investigator: Glenn S. Smith

Work Unit Eight: *Microwave Holography in Near- and Far-Field Measurements*
Principal Investigator: Edward B. Joy

3 Degrees Awarded

1. Thomas R. Gardos – Ph.D, June 1993
   Thesis Title: *Analysis and Design of Multidimensional FIR Filter Banks,*

2. Stephen A. Martucci – Ph.D., June 1993
   Thesis Title: *Symmetric Convolution and the Discrete Sine and Cosine Transforms: Principles and Applications,*

3. G. Vines – Ph.D., June, 1993
   Thesis Title: *Signal Modeling with Iterated Function Systems*

4. George C. Brown – Ph.D., June 1993
   Thesis Title: *Angle of Arrival Estimation Utilizing Hybrid Arrays*

5. Brian L. Evans – Ph.D., June 1993
   Thesis Title: *A Knowledge-Based Environment for the Design and Analysis of Multidimensional Multirate Signal Processing Algorithms*

6. Gregory N. Henderson – Ph.D., September 1993
   Thesis Title: *Semiconductor Quantum Electron Wave Transport, Diffraction and Interference: Analysis, Devices, and Measurement*

7. Jose Crespo – Ph.D., December, 1993
   Thesis Title: *Morphological connected filters and intra-region smoothing for image segmentation,*

8. Daniel W. Wilson – Ph.D., March 1994
   Thesis Title: *Optical Waveguiding in Photorefractive Crystals and Electron Waveguiding in Semiconductor Nanostructures*

9. Mehdi Khosravi – Ph.D., June 1994
   Thesis Title: *Morphological Approaches to Linear Filter Implementation and Template Matching*

10. Donald N. Black – Ph.D., June 1994
    Thesis Title: *Test Zone Field Compensation*

11. Ali Adibi – M.S., September 1994
    Thesis Title: *Design of Infrared Emitters and Detectors based on Quasibound States in Semiconductor Quantum Structures*

12. Iraj Sodagar – Ph.D., December 1994
    Thesis Title: *Analysis and Design of Time Varying Filter Banks*

13. J. Huang – Ph.D., March 1995
    Thesis Title: *Motion Estimation and Compensation for Video Image Sequences,*

14. Lina J. Karam – Ph.D., March 1995
    Thesis Title: *Design of Complex Digital FIR Filters in the Chebyshev Sense,*

15. Richard Rau – M.S., March 1995
    Thesis Title: *Correction of the Proximity Effect in Nanolithography*

16. K. L. Shlager – Ph.D., March 1995
    Thesis Title: *The Analysis and Optimization of Bow-Tie and TEM Horn Antennas for Pulse Radiation using the Finite-Difference Time-Domain Method*

17. Carlos C. Davis – Ph.D., December 1995
    Thesis Title: *Iterative Algorithms for the Reconstruction of Multidimensional Signals from their Projections,*

18. Bauldine-Brunel Paul – Ph.D., June 1995
    Thesis Title: *Video Compression Based on Iterated Function Systems*

4 Publications

4.1 Work Unit One: Multidimensional Digital Signal Processing and Modeling

1. Thomas R. Gardos, *Analysis and Design of Multidimensional FIR Filter Banks,* Ph.D. Thesis, Georgia Institute of Technology, June 1993.

2. Stephen A. Martucci, *Symmetric Convolution and the Discrete Sine and Cosine Transforms: Principles and Applications,* Ph.D. Thesis, Georgia Institute of Technology, May 1993.

3. D. Y. Suh, R. M. Mersereau, R. L. Eisner, and R. I. Pettigrew, "Knowldege-based system for boundary detection of four-dimensional cardiac magnetic resonance image sequences," *IEEE Trans. Medical Imaging,* vol. 12, No. 1, pp. 65–72, March 1993.

4. J. Huang and R. M. Mersereau, "Contour-based hybrid displacement estimation for image sequence compression," *Proc. 1993 IEEE Int. Conf. Acoustics, Speech, Signal Processing,* vol. 5, pp. 433–436.

5. F. J. Malassenet, "Texture coding using a pyramid decomposition," *Proc. 1993 IEEE Int. Conf. Acoustics, Speech, Signal Peocessing,* vol. 5, pp. 352–356.

6. S. A. Martucci and R. M. Mersereau, "The symmetric convolution approach to the nonexpansive implementation of FIR filter banks for images," *Proc. 1993 IEEE Int. Conf. Acoustics, Speech, Signal Processing,* vol. 5, pp. 65–68.

7. S. A. Martucci and R. M. Mersereau, "New approaches to block filtering of images using symmetric convolution and the DST and DCT," *Proc. 1993 IEEE Int. Symp. Circuits Systems,* pp. 259–262.

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11. C. C. Davis, *Iterative Algorithms for the Reconstruction of Multidimensional Signals from their Projections,* Ph.D.Thesis, Georgia Institute of Technology, Nov. 1995.

12. J. Huang, *Motion Estimation and Compensation for Video Image Sequences,* Ph.D. Thesis, Georgia Institute of Technology, March 1995.

13. K. K. Truong and R. M. Mersereau, *Vector Quantization Video Encoder using Hierarchical Cache Memory Scheme,* U.S.Patent #5,444,489, Aug. 22, 1995.

14. S. D. Bayrakeri and R. M. Mersereau, "A new method for directional interpolation of images," *Proc. 1995 IEEE Int. Conf. Acoustics, Speech, Signal Processing,* vol. 4 , pp. 2383–2386.

15. F. H. Lin and R. M. Mersereau, "A constant subjective quality MPEG," *Proc. 1995 IEEE Int. Conf. Acoustics, Speech, Signal Processing,* vol. 5, pp. 433–436.

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17. J. Huang and R. M. Mersereau, "A modified gradient inverse filter for image noise suppression," *1995 Int. Conf. Signal Processing Applications and Technology.*

18. T. R. Gardos, K. Nayebi, and R. M. Mersereau, "Filter bank impulse response and the equivalence of perfect reconstruction constraints," *IEEE Trans. Image Processing,* accepted for publication.

4.2 Work Unit Two: Iterated Function Systems and Stereo Image Processing

1. G. Vines, "Signal Modeling with Iterated Function Systems," Ph.D. Thesis, Georgia Institute of Technology, June

2. G. Vines and M.H. Hayes, "Adaptive IFS image coding with proximity maps," *Proc. 1993 Int. Conf. on Signal Processing*, pp. V349-V352, April 1993.

3. S. Liu and M.H. Hayes, "Video compression using quadtree segmentation and component equalization," *Proc. 1993 Int. Conf. on Signal Processing*, pp. V429-V432, April 1993.

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11. B.-B. Paul and M.H. Hayes, "Fractal-based compression of motion video sequences", *1994 Int. Conf. on Image Proc.*, Sept. 1994.

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21. H. Aydinoglu, F. Kossentini, and M.H. Hayes, "A new framework for multiview image coding", *Proc. 1995 Int. Conf. on Acoustics, Speech, and Signal Processing*, pp. 2173-2176, May 1995.

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4.3 Work Unit Three: Morphological Systems for Multidimensional Signal Processing

1. J. Crespo, *Morphological connected filters and intra-region smoothing for image segmentation,* Ph.D. Thesis, School of Electrical and Computer Engineering, Georgia Institute of Technology, December, 1993.

2. L. Hertz and R. W. Schafer, "Measurement of Edge Coincidence in Image Thresholdings," *Journal of Visual Communication and Image Representation*, Vol. 4, No. 2, June 1993, pp. 149-156.

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17. J. Crespo, J. Serra, and R. W. Schafer, "Theoretical Aspects of Morphological Filters by Reconstruction," *Signal Processing*, vol. 47, pp. 201-225, 1995.

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1. George C. Brown, *Angle of Arrival Estimation Utilizing Hybrid Arrays*, Ph.D. Thesis, Georgia Institute of Technology, May 1993.

2. Brian L. Evans, *A Knowledge-Based Environment for the Design and Analysis of Multidimensional Multirate Signal Processing Algorithms*, Ph.D. Thesis, Georgia Institute of Technology, June 1993.

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4. I. Sodagar, T. Barnwell, K. Nayebi, and M. Smith, "A new approach to time-varying filter banks," *Asilomar Conference on Signals, Systems, and Computers*, October 1993.

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9. Iraj Sodagar, *Analysis and Design of Time Varying Filter Banks*, Ph.D. Thesis, Georgia Institute of Technology, November 1994.

10. B. L. Evans, T. R. Gardos, and J. H. McClellan, "Imposing Structure on Smith Form Decompositions of Rational Resampling Matrices", *IEEE Trans. on Signal Processing,* vol. 42, no. 4, pp. 970–973, April, 1994.

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16. I. Sodagar, T. P. Barnwell, and M. J. T. Smith, "On the Statistical Optimality of FIR Filter Bank Design," *Proceedings of the IEEE DSP Workshop*, Yosemite, CA, October 1994.

17. L. J. Karam, *Design of Complex Digital FIR Filters in the Chebyshev Sense,* Ph.D. Thesis, Georgia Institute of Technology, March 1995.

18. R. Rau, *Correction of the Proximity Effect in Nanolithography,* M.S. Thesis, Georgia Institute of Technology, March 1995.

19. M. J. T. Smith and W. Chung, "Recursive Time-Varying Filter Banks for Subband Image Coding," *Trans. on Signal Processing*, pp. 885–896, July 1995.

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24. Karam, L. J. and J. H. McClellan, "Efficient Design of Families of FIR Filters by Transformation," *1996 Intl. Conf. on Acoustics, Speech and Signal Processing,* Atlanta, GA, May 1996.

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